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Multilevel Converters in Renewable Energy Systems

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1. Introduction

In the current global climate, demand for a renewable energy system has increased due to environmental issues and limited fossil resources. Along with this demand, Photovoltaic (PV) and Wind Turbine (WT) systems have become the most common type of the grid connected renewable energy systems (Carrasco, 2006). However, to connect these systems to the grid, output voltage and frequency adjustment are the challenging issues. Various types of converters have been utilized to provide grid connected renewable energy systems. In PV or Fuel Cell (FC) applications, DC-DC converters are required to adjust the variable and low quality output voltage of the PV panels or fuel cells. A DC-AC converter is employed to generate desired voltage and frequency for the grid connection. As well, an AC-DC-AC converter is necessary for the WT systems as wind energy is variable during the system operation.
In response to the growing demand for medium and high power applications, multilevel inverters have been attracting growing consideration in variable speed WT and PV systems recently (Tolbert & Peng, 2000; Clasis & Agelidis, 1998). Multilevel converters enable the output voltage to be increased without increasing the voltage rating of switching components, so that they offer the direct connection of renewable energy systems to the grid voltage without using the expensive, bulky, and heavy transformers. In addition, multilevel inverters synthesis stair case output voltage which is closer to sinusoidal voltage using DC link voltages compared with two-level inverter. Synthesising a stepped output voltage allows reduction in harmonic content of voltage and current waveforms and eventually size of the output filter. Among different types of the multilevel converters, cascade converters is usually used in PV applications due to its modularity and structure (Alonso, 2003). However, the number of switches is more than the other types of multilevel converters and needs several separated DC sources. The diode-clamped converter is another type of multilevel converters which is widely used in transformerless grid connected systems due to its minimum number of active power components and shared DC link voltage (Busquets-Monge, 2008). Due to the structure of the diode-clamped converter, it suffers from neutral point voltage balancing. Although a solution for capacitor voltage balancing has been addressed in literature (Yazdani, 2005), this increases the complexity of the control strategy. Also, existing methods are not applicable for all numbers of levels and modulation indexes. Furthermore, the use of auxiliary devices or active rectifiers has been proposed to balance

the DC link capacitors but these can increase the cost and complexity of the system (Marchesoni, 2002).
In photovoltaic, fuel cells and storage batteries, the low output DC voltage should be boosted. Therefore, a step-up converter is necessary to boost the low DC voltage for the DC link voltage of the inverter. The main contribution of this chapter is to electrical energy conversion in renewable energy systems based on multilevel inverters. Different configuration of renewable energy systems based on power converters will be discussed in detail. Finally, a new single inductor Multi-Output Boost (MOB) converter is proposed, which is compatible with the diode-clamped configuration. Steady state and dynamic analyses have been carried out in order to show the validity of the proposed topology. Then the joint circuit of the proposed DC-DC converter with a three-level diode-clamped converter is presented in order to have a series regulated voltage at the DC link voltage of the diode-clamped inverter. MOB converter can boost the low input DC voltage of the renewable energy sources and at the same time adjust the voltage across each capacitor to the desired voltage levels, thereby solving the main problem associated with capacitor voltage imbalance in this type of multilevel converter.

2. Power Conversion Systems

Power electronic converters are a family of electrical circuits which convert electrical energy from one level of voltage, current, or frequency to another using power switching components (Zare, 2008). In all power converter families, energy conversion is a function of different switching states. The process of switching the power devices in power converter topologies from one state to another is called modulation. Regarding different applications, various families of power converters with optimum modulation technique should be used to deliver the desired electrical energy to the load with maximum efficiency and minimum cost. Three main families of power converters which are usually used in renewable energy systems are:

- AC-DC converters
- DC-DC converters
- DC-AC converters

Fig. 1 shows a scheme of electrical conversion according to the different family of power converters used in renewable energy systems.

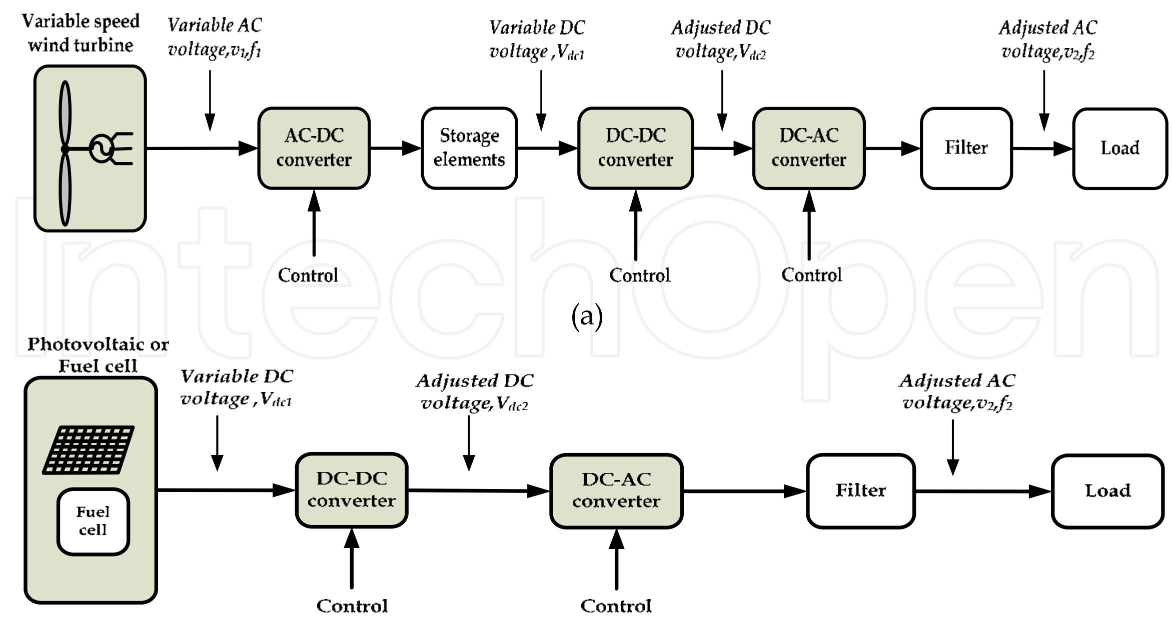


Fig. 1. Families of power converters categorized according to their energy conversion in renewable energy systems

In renewable energy systems, sources can be either AC or DC such as WT or PV systems, respectively. However, due to the load requirement, the power may be changed to DC or AC. Therefore, based on different applications, proper combination and control of above power converters can supply a load. As shown in Fig.1 (a), in residential applications or grid connected systems where the variable voltage of renewable energy systems should be converted to achieve desirable AC voltage and frequency, AC-DC, DC-DC and DC-AC converters may be needed. On the other hand, when the input voltage is variable DC source (Fig.1(b)) such as PV or FC systems, DC-DC converter combined with DC-AC converter may be used to have a regulated AC waveform for residential or grid connected systems.

2.1 AC-DC Converter

A three-phase low frequency rectifier is depicted in Fig.2 (a). This converter operates at line frequency, so that the switching happens at 50Hz or 60Hz. Low frequency rectifiers are made up by diode or thyristor to change the AC voltage to DC. However, rectifiers based on thyristors have a freedom to change the firing angle to switch the thyristor, so that the amount of output DC voltage is controlled compared with diode rectifier. Using a capacitor at output can increase the quality of output voltage.

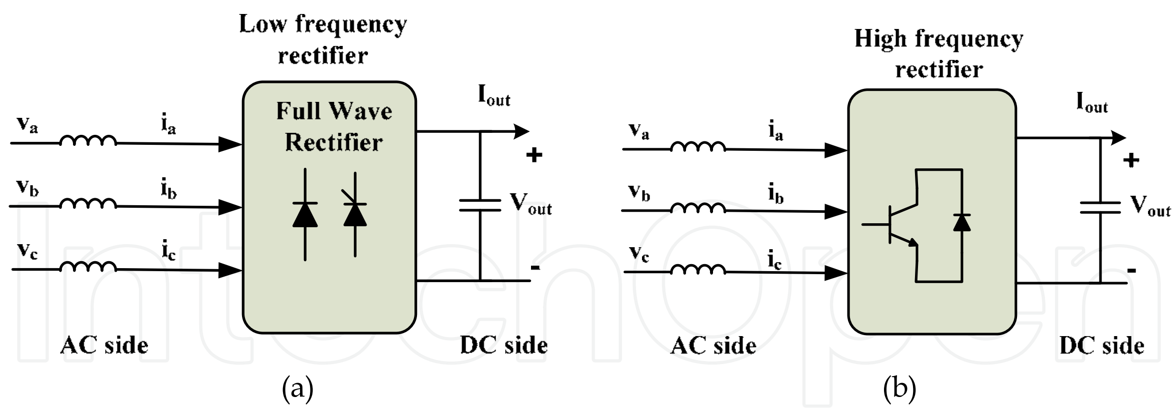


Fig. 2. AC-DC converter (a) low frequency (b) high frequency

A three-phase controlled high frequency converter based on IGBT is shown in Fig.2 (b). This circuit can change the input AC voltage into DC voltage. By controlling the duty cycle of the switches based on different modulation technique, the amount of output DC voltage can be controlled. Since the switches drive in high frequency, the amount of harmonic content in current waveform is decreased. In addition, this configuration can provide bidirectional power flow between load and source.

2.2 DC-DC Converter

DC-DC converters are a kind of high frequency converters which convert unregulated DC power to regulated DC power. Since the output voltage of renewable energy systems or rectifier converter is basically unregulated DC voltage, as shown in Fig. 3, DC-DC converters are necessary to adjust the DC voltage for different applications. Three basic configurations of DC-DC converters are buck, boost and buck-boost converters.

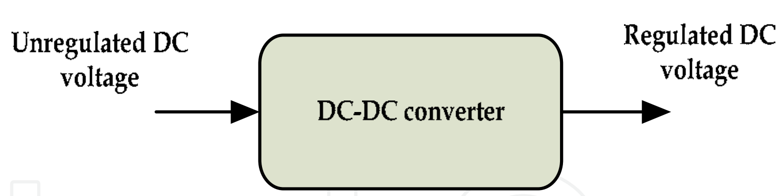


Fig. 3. DC-DC converter

In a buck converter the output voltage is normally less than input voltage. However, a boost converter has the ability to increase the input voltage based on duty cycle of the switch. A buck-boost converter can either buck or boost the input voltage. A boost converter is usually applied in renewable energy systems as the output voltage of these systems is low and unregulated. Configuration of the boost converter is illustrated in Fig. 4. In this converter, output voltage is a function of the duty cycle of switch (S) which can be defined by a proper modulation technique. When the switch is on, the inductor can be charged by the current flowing through it. However, in the next subinterval when the switch is turned off, the capacitor will be charged by the inductor current. Second order LC filter in this configuration can regulate the output voltage and remove the high frequency harmonics.

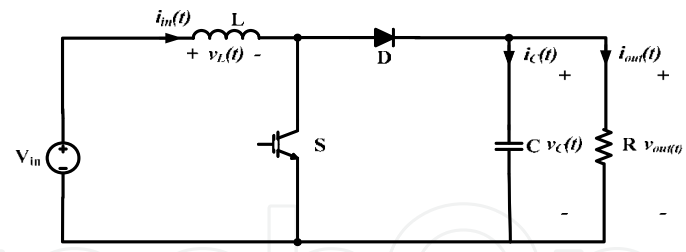


Fig. 4. Schematic configuration of a DC-DC boost converter

2.3 DC-AC Converter

A block diagram of a voltage source converter is shown in Fig. 5. In this configuration the input source is a voltage which is stored in DC link capacitor. This converter chops the input DC voltage and generates an AC voltage with desired magnitude and frequency with respect to the pulse patterns and modulation techniques. Different current and voltage control methods have been proposed to generate a high voltage high current rectangular waveform based on reference voltage characteristics (Nami & Zare, 2008).

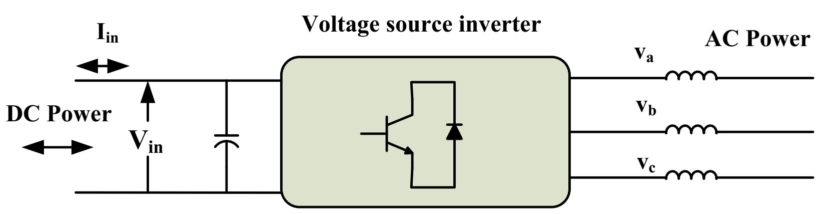


Fig. 5. DC-AC voltage source converter

One leg of a classical voltage source inverter is shown in Fig. 6 (a). Based on this configuration, when S_1 turns on, leg voltage (V_{an}) is V_{dc} and when S_1 turns off, V_{an}=0. Therefore, two different voltage levels appear at the leg voltage. Single-phase and three-phase structure can be constituted by the connection of one and two legs to this structure, respectively. Fig. 6 (b) shows a single-phase inverter. Output voltage levels based on different switching states are given in Table. 1. As shown, three voltage levels appear in output voltage. Different high and low frequency PWM techniques can be applied to generate the reference voltage. Leg voltages and output voltage waveforms of a single-phase inverter are shown in Fig. 7.

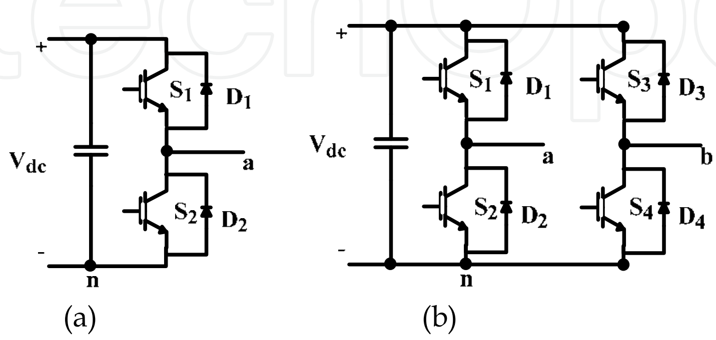


Fig. 6. Classical voltage source inverter (a) one leg structure (b) single-phase inverter

S_1	S_3	V_{an}	V_{bn}	V_{ab}
off	off	0	0	0
off	on	0	V_{dc}	$-V_{dc}$
on	off	V_{dc}	0	V_{dc}
on	on	V_{dc}	V_{dc}	0

Table 1. Switching states of classical voltage source inverter

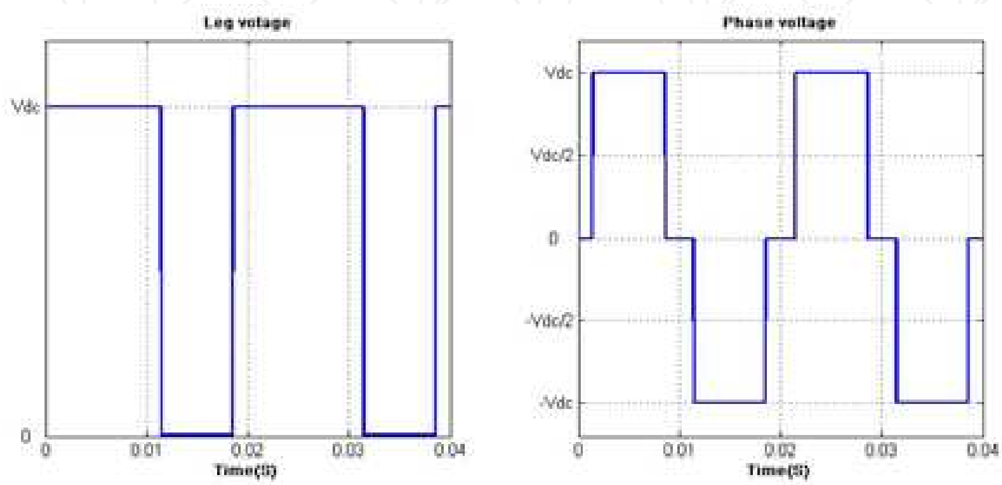


Fig. 7. Leg voltages and output voltage of single-phase inverter

3. Multilevel Topologies

Multilevel converters have many advantages for medium and high power systems as they synthesise a higher output voltage than the voltage rating of each switching device. Stepped output voltage allows a reduction in harmonic content of voltage and current waveforms, switching frequency, and semiconductors voltage level. The presented merits make multilevel converters appropriate for medium and high voltage renewable energy applications. The best known multilevel topologies (Rodriguez et al., 2002) are diode-clamped, flying capacitor, and cascade inverter, the latter being normally considered for PV application. However, the diode-clamped converter is the most popular converter in renewable energy systems due to its structure. Different current (Zare & Ledwich, 2002; Zare & Ledwich, 2008) and voltage control (Leon et al., 2008) techniques have been proposed for multilevel converters to have an optimum efficiency. Although each type of multilevel converters share the advantages of multilevel voltage source inverters, they may be suitable for specific application due to their structures and drawbacks. Operation and structure of the three main types of multilevel converters are discussed in the following sections.

3.1 Diode-clamped Inverter

Concept of the diode clamped topology was proposed by Nabae (Nabae et al., 1981). This topology has found wide acceptance for its capability of high voltage, and high efficiency operation. A phase leg of a three-level diode-clamped inverter is shown in Fig. 8 (a). It consists of two pairs of switches and two diodes. Each switch pairs works in complimentary mode and the diodes are used to provide access to mid-point voltage. The DC bus voltage is split into three voltage levels by using two series connection of DC capacitors, C_1 and C_2. Each capacitor is supposed to have an equal DC voltage and each voltage stress will be limited to one capacitor level through clamping diodes (D_{c1} and D_{c2}). If assumed that total DC link voltage is V_{dc} and mid point is regulated at half of the DC link voltage, the voltage across each capacitor is $V_{dc}/2$ ($V_{c1}=V_{c2}=V_{dc}/2$). Based on the structure of the diode-clamped converter, there are three different possible switching states which apply the staircase voltage on output voltage relating to DC link capacitor voltage rate. Switching states of the three-level converter are summarized in Table 2. To study the effect of the number of output voltage levels in diode-clamped topology, Fig. 8 (b) shows a phase leg of a four-level inverter. If converter works in balance condition, DC link voltage is split in three equal values by the series capacitors ($V_{c1}=V_{c2}=V_{c3}=V_{dc}/3$). There are four different switching combinations shown in Table 3 which can generate four different voltage levels in output leg voltage (V_{an}).

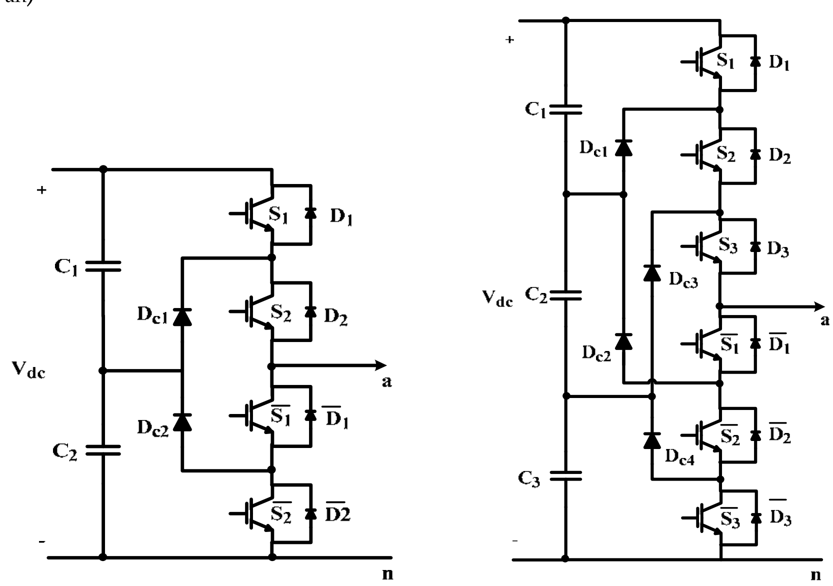


Fig. 8. One leg of diode-clamped converter (a) three-level (b) four-level

According to Fig.6, by connecting another leg named as leg (b) to the above configurations, five and seven voltage levels can be achieved in the output voltage (V_{ab}) of three and four level inverters. Fig. 9 and Fig. 10 show the leg voltage and phase voltage of the three and four level inverters in the balance condition, respectively.

S_1	S_2	Leg voltage (V_{an})
on	on	V_{dc}
off	on	$V_{dc}/2$
off	off	0

Table 2. Switching states in one leg of the three-level diode-clamped inverter

S_1	S_2	S_3	Leg voltage (V_{an})
on	on	on	V_{dc}
off	on	on	$2V_{dc}/3$
off	off	off	$V_{dc}/3$
off	off	off	0

Table 3. Switching states in one leg of the four-level diode-clamped inverter

Improvement in quality of the output voltage is obvious by increasing the number of voltage levels as the voltage waveform becomes closer to sinusoidal waveform (Nami et al., 2008). However, capacitor voltage balancing will be the critical issue in high level converters due to the existence of DC currents in the middle points of the DC link. Thus, capacitor are either charged or discharged for some intervals which limit the practical operation of the high-level diode-clamped converters in some conditions. This issue should be taken into account in this inverter. MOB joint with diode-clamped inverter in the following sections address this problem for renewable energy systems. In general in a converter with n series DC link capacitors, $m= (n+1)$ leg voltage levels and $l=2×m-1$ phase voltage levels can be achieved in output waveforms.

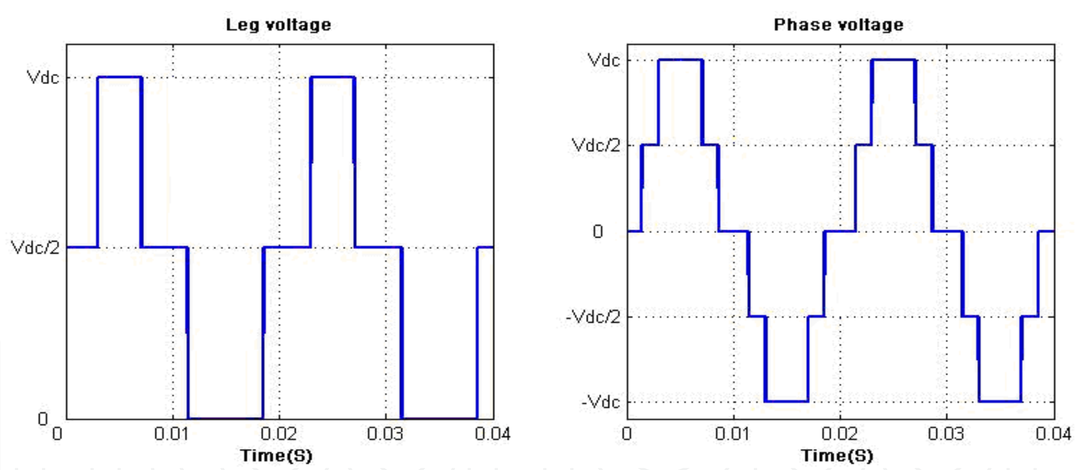


Fig. 9. Output voltage in three-level diode-clamped inverter (a) leg voltage (b) output voltage

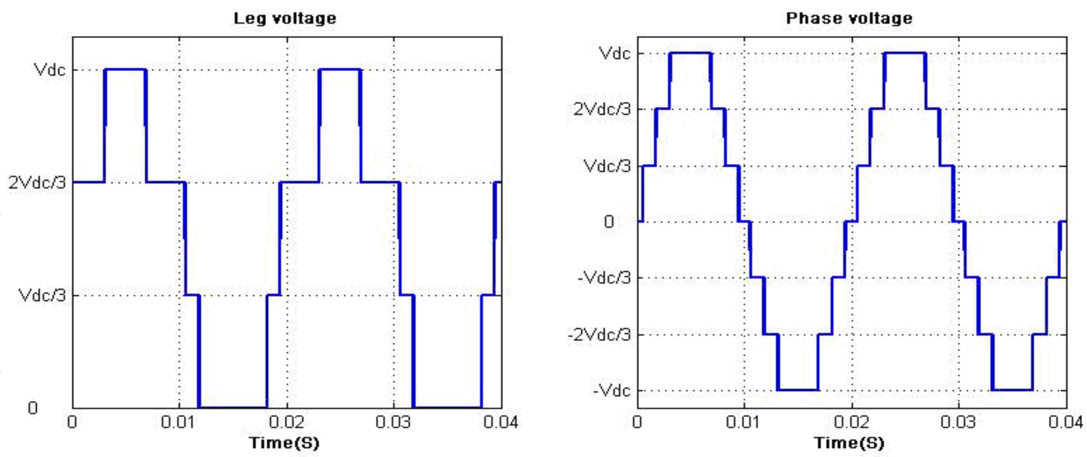


Fig. 10. Output voltage in four-level diode-clamped inverter (a) leg voltage (b) output voltage

3.2 Flying Capacitor Inverter

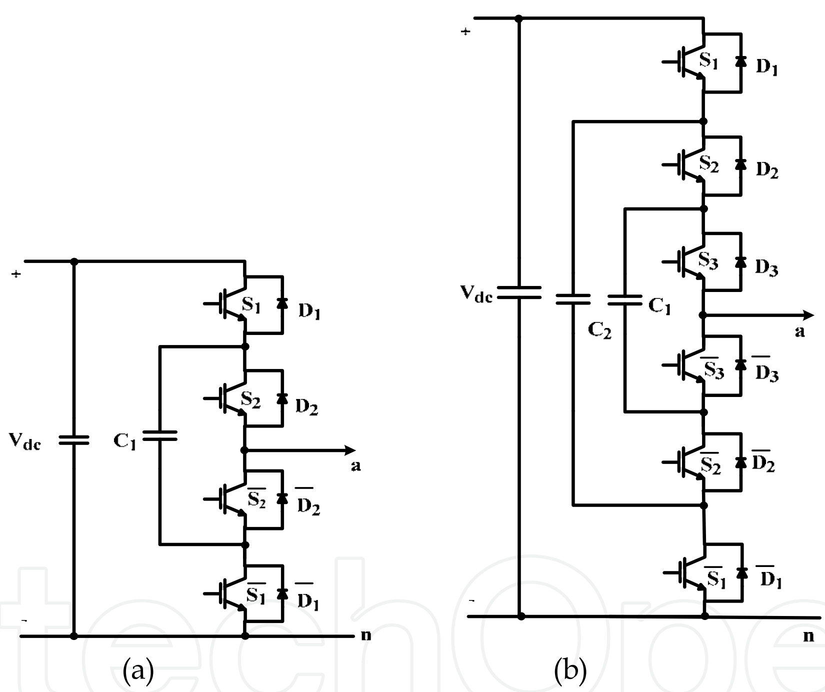


Fig. 11. A leg of flying capacitor converter (a) three-level (b) four-level

Fig. 11 shows the leg structure of a flying capacitor inverter. This configuration is an alternative to the diode-clamped converter, however, voltage across an open switch is constrained by clamping capacitors instead of clamping diode in diode-clamped topology (Meynard & Foch, 1992). Therefore, it can avoid the use of multiple diodes at the higher voltage levels. Although this type of converter shares the advantages of all multilevel inverters, it faces with some problems. One of the main problems is the requirement of complicated control strategy due to regulation of floating capacitor voltages (Zare & Ledwich, 2002). Another problem is associated with converter initialization that means before the flying capacitor inverter can be modulated, the clamping capacitors must be set up with the required voltage level. By increasing the number of levels, more capacitors are needed (Bum-Seok et al. 1998). If the input DC link is V_{dc} and the flying capacitor works in balance condition mode, in order to have an equal step voltages at output voltage, clamped capacitor should regulated at $V_{c1}=V_{dc}/2$ in the three-level inverter and $V_{c2}= 2V_{c1}=2V_{dc}/3$ in the four-level inverter. It is note that along with increasing the output voltage quality in four-level structure, voltage stress on switching components reduces by $V_{dc}/6$.

Different leg voltage levels associated with different switching states in three and four level flying capacitor inverters are given in Table 4 and 5, respectively. It is clear that one more voltage level is available in four-level inverter. Although the output voltage levels in the flying capacitor inverter is similar to the diode-clamped converter, there are more than one switching state available to achieve the specific level which is called redundant switching states. These redundant switching vectors give freedom to balance the clamped capacitor voltages as they may provide different current loops through the capacitors.

S_1	S_2	Leg voltage (V_{an})
off	off	0
off	on	$V_{dc}/2$
on	off	$V_{dc}/2$
on	off	V_{dc}

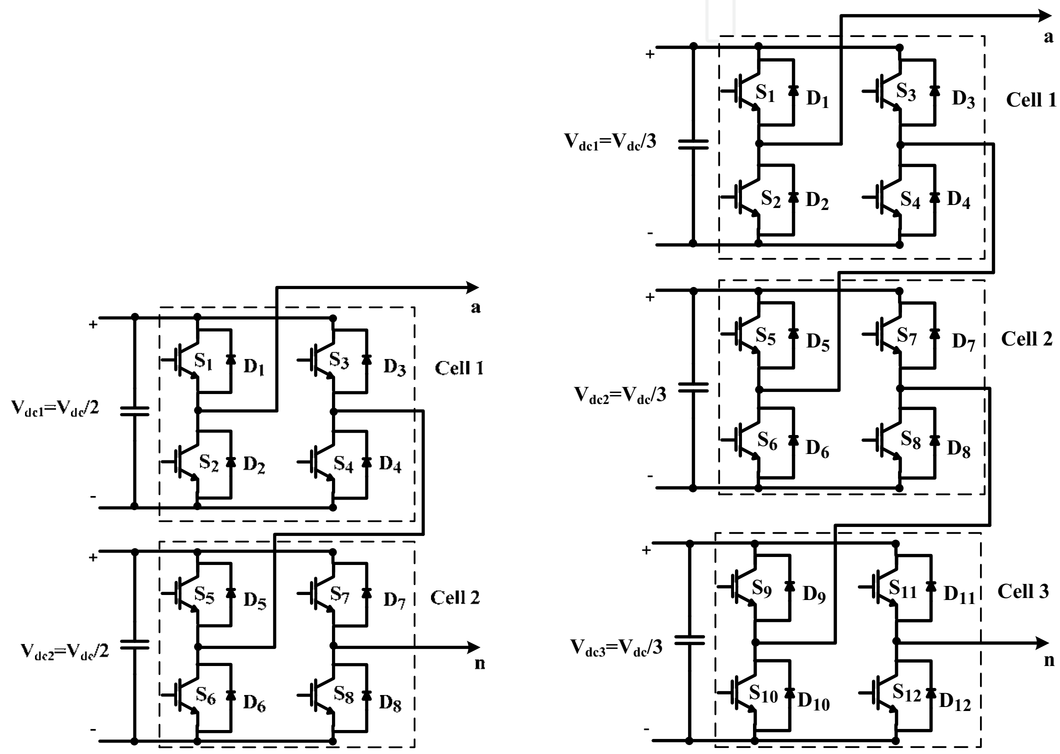
Table 4. Switching states of three-level flying capacitor inverter

S_1	S_2	S_3	Leg voltage(V_{an})
off	off	off	0
off	off	on	$V_{dc}/3$
off	on	off	$V_{dc}/3$
off	on	on	$2V_{dc}/3$
on	off	off	$V_{dc}/3$
on	off	on	$2V_{dc}/3$
on	on	off	$2V_{dc}/3$
on	on	on	V_{dc}

Table 5. Switching states of four-level flying capacitor inverter

3.3 Cascade Inverter

The third topology for a multilevel converter is the cascade inverter, which can be synthesised by a series of single-phase full-bridge inverters. Assuming that the DC voltage of each full-bridge cell is same and equal to $V_{dc}/2$, each full-bridge inverter can switch between $-V_{dc},/2$,0, and $V_{dc},/2$. Therefore, by adding and subtracting of the output voltage levels of the two cascaded full-bridge inverter cells, five different voltage levels can be achieved in the output voltage in Fig. 12 (a). Switching states associated with different output voltage levels for the cascade inverter with two full-bridge inverter cells are demonstrated in Table 6. Three-phase configuration can be easily implemented by three single-phase structures. Cascade configuration has been attracted for medium and high voltage renewable energy systems such as photovoltaic, due to its modular and simple structure (Alonso et al., 2003). A higher level can easily be implemented by adding classical H-bridge cells in this configuration. However, it needs additional DC voltage sources and switching devices which can increase the cost of the system.



(a) (b)

Fig. 12. One phase leg of cascade inverter (a) five-level (b) seven-level

By adding each cell, two more voltage levels can be achieved in output voltage which can reduce the harmonic distortion. Fig. 12 (b) demonstrates the cascade inverter with three full-bridge inverter cells where each cell endures $V_{dc}/3$ of the total high input DC voltage (V_{dc}). It is clear that in comparison with two-cell cascaded inverter, to achieve two more voltage levels at output and reduce the voltage stress on each cell in cascade inverter topology, four extra switches and one isolated DC source should be paid. In general, cascade converter with n-full-bridge inverter cells can synthesis l=(2n+1) voltage levels at the output voltage of each phase structure.

S_1	S_3	S_5	S_7	Leg voltage (V_{an})
off	off	off	off	0
off	off	off	on	$-V_{dc}/2$
off	off	on	off	$V_{dc}/2$
off	off	on	on	0
off	on	off	off	$-V_{dc}/2$
off	on	off	on	$-V_{dc}$
off	on	on	off	0
off	on	on	on	$-V_{dc}/2$
on	off	off	off	$V_{dc}/2$
on	off	off	on	0
on	off	on	off	V_{dc}
on	off	on	on	$V_{dc}/2$
on	on	off	off	0
on	on	off	on	$-V_{dc}/2$
on	on	on	off	$V_{dc}/2$
on	on	on	on	0

Table 6. Switching states of five-level cascade inverter

The hybrid converter proposed by Manjrekar (Manjrekar et al., 2000) is a cascaded structure that has been modified, such that the DC link of full-bridge inverters has unequal DC source voltages. Therefore, based on different switching states it is possible to achieve more voltage levels in output voltage by adding and subtracting DC link voltages compared with conventional multilevel inverters with the same number of components. Diverse topologies have been studied based on a variety of H-bridge cascaded cells and DC voltage ratio to enhance the output voltage resolution compared with the same DC voltage ratio of the cells.

4. Application of Power Electronics in Renewable Energy Systems

Nowadays, the electrical power generation from renewable energy sources has become a focal point in research because of environmental problems and a perceived of traditional energy sources in the near future. Since last decade, researchers have been working on electrical systems for variable speed wind turbines. The main advantages of variable speed are noise reduction, maximum power tracking, and proper controlled torque and in this manner, the possibility to damp resonance and avoid speeds causing resonance. Several electrical systems have been presented to connect the wind turbine with variable speed and frequency to the constant voltage and frequency of the network. The main aspects of these topologies are increased efficiency and robustness, a decrease in the size and maintenance of the system and eventually reduction of whole system expense.

On the other hand, grid connected photovoltaic (PV) systems, mostly single-phase PV systems and their contribution to clean power generation, is recognized more and more worldwide. The main advantages of PV system are long life time, high efficiency and good environmental condition. The most important issues for grid connected PV to gain wide acceptance are reliability and low cost. There are two approaches to achieve high voltage and high efficiency, one is to connect the cells in series to generate high voltage DC and use

high voltage DC to an AC inverter circuit. However, this configuration needs high voltage rate devices for the inverter. Another approach is to use low voltage devices for the inverter and then step up the voltage using transformers. This can increase losses and cost of system. Using transformerless concepts are advantageous with regard to their high efficiency and the resulting benefits of reduction in cost, size, weight and complexity of the inverter.
Another renewable energy source is fuel cells which are considered attractive for Distributed Generation (DG) applications. Fuel cells are electrochemical devices that convert the chemical energy of fuel and oxidant directly to electrical energy and heat. In fuel cell powered applications, a fuel cell (low power) will supply the system, then a DC-DC converter is used to boost the low voltage of the fuel cell to make a high voltage DC link. A DC-AC inverter is used to obtain AC voltage to feed the load.
In some high voltage, high power wind turbine or photovoltaic systems, if protection is not a big issue, multilevel inverters are a suitable configuration in transformerless grid connected systems (Lopez et al., 2006). Multilevel converters synthesise a higher output voltage than the voltage rating of each switching device so that they can provide a direct connection of renewable energy systems to the grid. Even in grid connected systems with a transformer, multilevel inverters are suitable topologies due to low Total Harmonic Distortion (THD) and low voltage stress (dv/dt) which minimise EMI, and also switching losses compared to traditional converters. In addition, the above advantages will lead to reduction of the cost and size of the output filter in the systems based on multilevel converters.

4.1 Variable Speed Wind Turbine Systems

This topology basically employs induction or synchronous machine as a generator. The power electronics converter in this topology might be created by either a diode rectifier with boost chopper converter connected to the PWM inverter or two bidirectional PWM-VSI connected back-to-back (Carrasco et al., 2006). Extracting as much power as possible from wind energy and feeding high quality electricity to the grid are the two main objectives of these systems. As shown in Fig. 13, power converters comprise rectifier in generator side and inverter in grid side which are connected together through DC link. This scheme allows, on one hand control of the active and reactive powers of the generator, and on the other hand, a reduction of the harmonics of current waveform by the power converter. In order to benefit from advantages of multilevel inverters in such a system, generator and grid side inverters can be utilized based on the diode-clamped converter as it has shared DC link in its structure (Bueno et al., 2008).

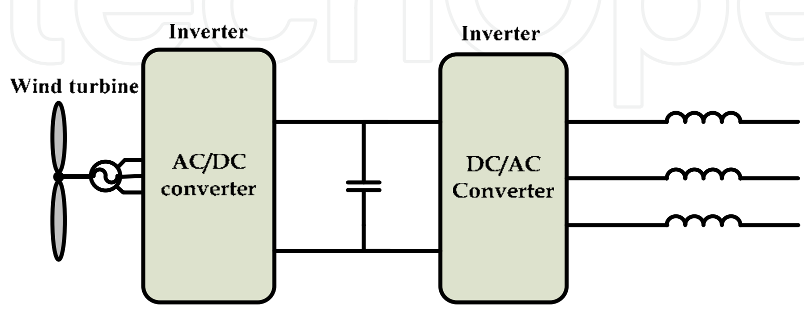


Fig. 13. Power conversion in WT systems using back-to-back configuration

An alternative to the power conversion system of a wind turbine is to use synchronous or permanent magnet generator instead of the induction machine as shown in Fig. 14. The power converter in generator side is replaced by an AC-DC rectifier with step-up DC-DC converter. This is a low cost configuration when compared with back-to-back topology. As the wind energy is variable, the step-up converter is responsible to adapt the rectifier voltage to the DC link voltage of the inverter. Also, this structure may provide transformerless connection systems due to the DC level voltage regulation using boost converter. Using multilevel converters for medium and high voltage applications is advantageous based on this structure as they can increase the voltage without increasing the switching components voltage rate (Alepuz et al., 2006).

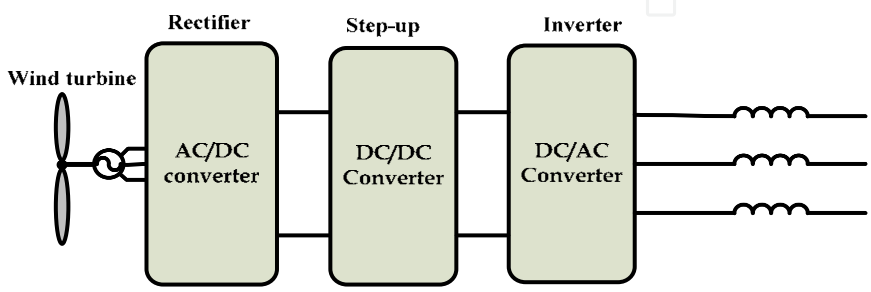


Fig. 14. Power conversion in WT systems using rectifier and step-up converter

4.2 Photovoltaic and Fuel Cell Systems

Photovoltaic and fuel cell systems are mostly attracted in single-phase residential applications with or without grid connection systems. The main advantages of these systems are long life time, high efficiency and good environmental condition. As output voltage of the PV and FC are low DC voltage, one approach for power conversion in this type of system is to use a low voltage inverter and then increase the AC voltage using transformers. However, it can increase losses and also the cost of the system. Alternative power connection topology demonstrated in Fig. 15, utilizes the DC-DC boost converter to generate high DC voltage for inverter DC link. Therefore, high voltage DC to AC inverter is necessary which can impose a high voltage rate for switching devices. To address this problem, multilevel converters such as diode-clamped or flying capacitor are a good candidate for this configuration that can increase the number of voltage levels without increasing the voltage rate of power components in DC-AC inverter (Myrzik, 2003; Sharma & Hongwei, 2006). A configuration of single-phase PV system with cascade converter is shown in Fig. 16. DC-DC converters are responsible for boosting the low input voltage and a cascade converter can synthesise a high voltage AC voltage by adding inverter cells output voltage. As mentioned before, cascade converter is a suitable topology for this kind of application as it needs separated DC voltage. However, a diode-clamped structure can be utilized in this configuration if DC link voltage capacitor voltage imbalance can be solved (Nami et al., 2008).

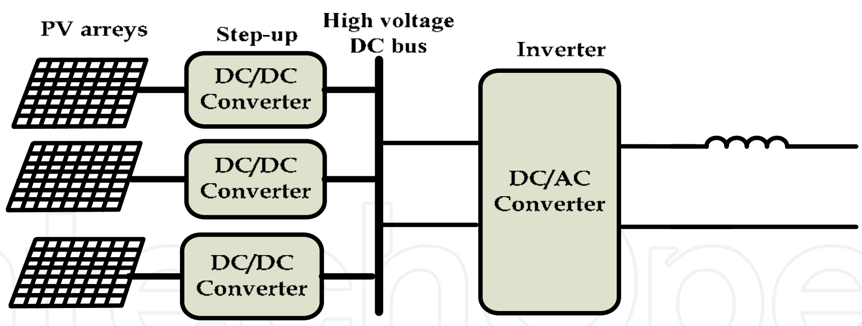


Fig. 15. Power conversion in transformerless PV systems

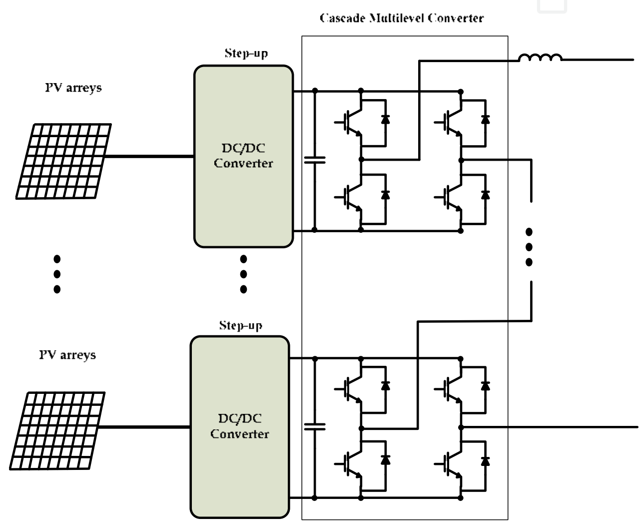


Fig. 16. Multilevel converter in transformerless PV systems

5. A New Topology for Multilevel Diode-clamped Converters in Renewable Energy Systems

DC link capacitor balancing is a challenging issue in the diode-clamped topology due to its series capacitors' connection. To address this limitation, isolated DC sources or alternatively, auxiliary converters can be used for capacitor voltage balancing. In this section, a new DC-DC boost converter with double outputs can be used as a front-end converter to boost the low output voltage of grid connected renewable systems based on the diode-clamped converter.

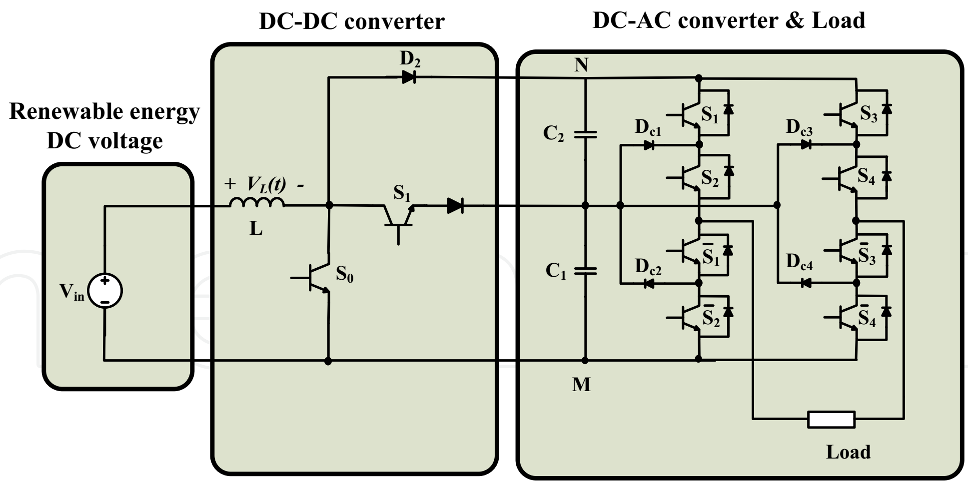


Fig. 17. Three-level diode-clamped topology joint with double-output MOB converter

Fig. 17 shows the proposed DC-DC converter connected to a three-level diode-clamped inverter. By controlling the proposed DC-DC converter, the DC link capacitors of the inverter can be regulated to the desired voltage level. Therefore, the MOB converter can address the capacitor voltage balancing in diode-clamped converters, which then will decrease the complexity of the inverter control strategy. Topology and control strategy of the MOB DC-DC converter is described in the next section.

6. Multi-output Boost Converter (MOB) Topology

Multi output DC-DC converters are efficient and economical devices which are used instead of several separate single output converters to make up a multi output power supply (Yunxiang & Jiuchao, 2004). Recently, several types of multi output DC-DC converters such as switched-capacitor, LLC resonant topology, cross regulation and parallel regulation techniques widely use in telecommunication, computers and industrial fields, are addressed in (Gu et al., 2005). A novel DC-DC converter with series capacitors in order to generate two different voltage levels for diode-clamped inverter is proposed by (Nami et al., 2007). It can also be applied for more voltage levels. This converter basically operates as a boost or buck converter based on duty cycles of the switches in each subinterval of the switching period. In this converter, by controlling the duty cycles of the switches in each subinterval, the output voltage can be controlled to provide the appropriate input DC voltage for the diode-clamped converter. This can avoid the capacitors voltage imbalance in the diode clamped topology. Moreover, by applying the presented topology in renewable energy systems, low rectified output-voltage can be boosted to a desired level.

6.1 Basic Circuit Configuration

A circuit diagram of the *N*-output boost converter is shown in Fig. 18 (a). This circuit consists of a boost switch S_0; $N\text{-}1$ sharing switches S_1 to S_{N-1}, N diodes (D_1 to D_N), an inductor, and N capacitors (C_1 to C_N) with different loads (R_1 to R_N).

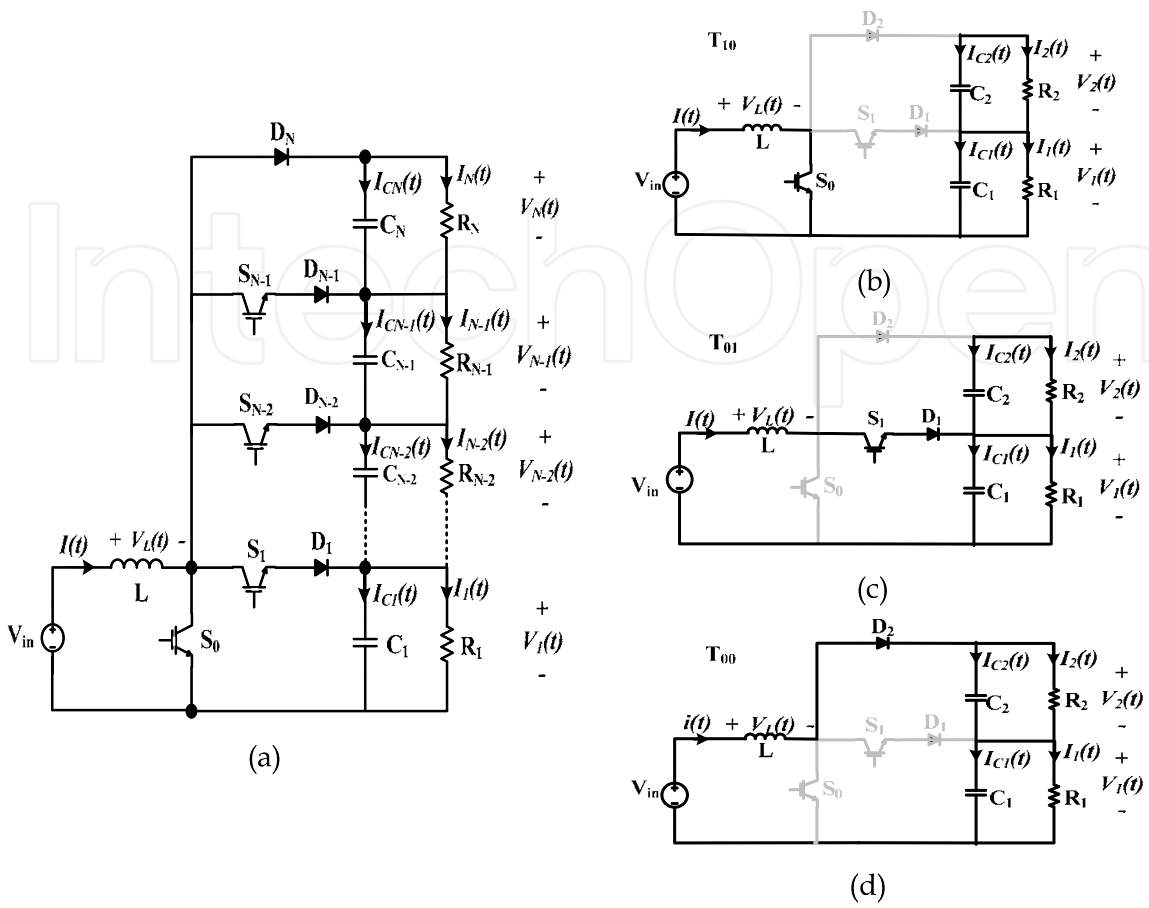


Fig. 18. Configuration of MOB converter (a) schematic; (b)-(d) equivalent circuit in different switching intervals for double-output (N=2)

Switching states	S_0	S_1	C_1	C_2
10	on	off	Discharge	Discharge
00	off	off	Charge	Charge
01	off	on	Charge	Discharge

Table 7. Switching states of double-output boost converter

In the subinterval zero, S_0 is turned "on" and the inductor can be charged by the current flowing through it. In the next N subintervals, S_0 remains "off" and the S_1 to S_{N-1} are switched to charge $N-1$ capacitors into the desired value. When S_1 to S_{N-1} are "off", the diode (D_N) directs the inductor current to charge all C_1 to C_N to generate V_1 to V_N, respectively. D_1 to D_{N-1} are used to block the negative voltage and provide two quadrant operation of S_1 to S_{N-1}. In a double-output converter there are three possible switching states as S_1 can not be turned "on" while S_0 is "on". The operation of the circuit in three different switching states has been summarised in Table 7 for N=2. The equivalent circuits of all switching states have been demonstrated in Fig. 18(b) to 18 (d).

6.2. Steady State and Dynamic Equations

To analyse the steady state performance of the MOB converter, time intervals of each switching are considered as T_{10}, T_{00}, and T_{01}. Then, switching period can be expressed as follows:

$$T_{10} + T_{00} + T_{01} = T \tag{1}$$

where, T is switching period. The average inductor voltage over one cycle should be zero in the steady state:

$$T_{10}(V_{in}) + T_{00}(V_{in} - V_1 - V_2) + T_{01}(V_{in} - V_1) = 0 \tag{2}$$

By definition of duty cycles in Eq.3 and substitution in Eq.2, it can be rewritten as follows:

$$\begin{cases} (D_0 + D_1)' = \dfrac{(T_{00})}{T} \\ D_0' = \dfrac{(T_{00} + T_{01})}{T} \end{cases} \tag{3}$$

$$V_{in} = (D_0')V_1 + (D_0 + D_1)'V_2 \tag{4}$$

where, V_{in} is input voltage and V_1 and V_2 are the bottom capacitor (mid point) and top capacitor voltages, respectively. Also, the average capacitor current over one cycle should be zero in the steady state.

$$\begin{cases} T_{10}(-\dfrac{V_1}{R_1}) + T_{00}(I - \dfrac{V_1}{R_1}) + T_{01}(I - \dfrac{V_1}{R_1}) = 0 \\ I = \dfrac{V_1}{R_1(D_0')} \end{cases} \tag{5}$$

$$\begin{cases} T_{10}(-\dfrac{V_2}{R_2}) + T_{00}(I - \dfrac{V_2}{R_2}) + T_{01}(-\dfrac{V_2}{R_2}) = 0 \\ I = \dfrac{V_2}{R_2(D_0 + D_1)'} \end{cases} \tag{6}$$

From Eq.4 to Eq.6, the steady state equation can be derived as follows:

$$\begin{cases} V_1 = \dfrac{n(D_0')V_{in}}{n(D_0')^2 + (D_0 + D_1)'^2} \\ V_2 = \dfrac{(D_0 + D_1)'V_{in}}{n(D_0')^2 + (D_0 + D_1)'^2} \\ I = \dfrac{V_{in}}{R_1(D_0')^2 + R_2(D_0 + D_1)'^2} \end{cases} \tag{7}$$

where, $n = \dfrac{R_1}{R_2}$. According to Eq.7, two different voltages can be obtained on output. Comparing this situation with the basic single output (V_1) Boost converter, although the total output voltage (V_T) in both converters is increased, in the MOB converter different output voltages can be obtained based on different duty cycles of the boost switch (S_0) and sharing switch (S_1) in steady state operations. Since the output voltage in Eq.7 is related to the load ratio, Table 8 shows some limitations to achieve diverse voltages that should be considered due to the fundamental nature of the circuit.

$V_1 = V_2$	$n = \frac{(D_0 + D_1)'}{D_0'}$
$V_1 > V_2$	$n > \frac{(D_0 + D_1)'}{D_0'}$
$V_1 < V_2$	$n < \frac{(D_0 + D_1)'}{D_0'}$

Table 8. Nature limitation of load ratio in different output voltage

Using an averaging method in each switching cycle, state equations can be developed for the dynamic analysis of inductor current or capacitor voltages in terms of systems variables. To construct a small-signal ac model at the quiescent operation (*I, V1, V2*), we can assume a small perturbation at the operating point. Thus, all input and output variables are defined as $x(t) = X + \hat{x}(t)$ where X is a DC amount and x (t) is an AC small-signal.

Regarding linearization method, Eq.8 shows the dynamic model space state of the proposed configuration.

$$\begin{bmatrix} L & 0 & 0 \\ 0 & C_1 & 0 \\ 0 & 0 & C_2 \end{bmatrix} \begin{bmatrix} \dot{i} \\ \dot{v}_1 \\ \dot{v}_2 \end{bmatrix} = \begin{bmatrix} 0 & -(D_0') & -(D_0 - D_1)' \\ (D_0') & -\frac{1}{R_1} & 0 \\ (D_0 - D_1)' & 0 & -\frac{1}{R_2} \end{bmatrix} \begin{bmatrix} i \\ v_1 \\ v_2 \end{bmatrix} + \begin{bmatrix} 1 & V_1 + V_2 & V_1 \\ 0 & -I & 0 \\ 0 & -I & -I \end{bmatrix} \begin{bmatrix} \hat{v}_{in} \\ \hat{d}_0 \\ \hat{d}_1 \end{bmatrix} \tag{8}$$

According to Eq.8, changing $(D_0+D_1)'$ and D_0' with a different ratio in a closed loop control system can keep the output voltages constant while the inductor current value has been modified. Developing this concept will lead to a current control strategy combined with voltage control to achieve the desired output voltage with a proper dynamic response. According to the steady state statements and dynamic model, the proposed MOB converter acts as a boost converter topology with a series of multiple output voltages.

6.3 MOB Converter with Multiple Outputs Configuration

Steady state and dynamic analysis can be extended for the proposed topology with multiple outputs (see Fig. 18 (a)). Rewriting the state space variables for N outputs:

$$\begin{bmatrix} L & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & C_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_i & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_j & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_k \end{bmatrix} \begin{bmatrix} \dot{i} \\ \dot{v}_1 \\ \vdots \\ \dot{v}_i \\ \vdots \\ \dot{v}_j \\ \vdots \\ \dot{v}_K \end{bmatrix} = \begin{bmatrix} 0 & -(1-D_0) & \cdots & -(1-\sum_{k=1}^{i} D_{K-1}) & \cdots & -(1-\sum_{k=1}^{j} D_{K-1}) & \cdots & -(1-\sum_{k=1}^{n} D_{K-1}) \\ (1-D_0) & \frac{1}{R_1} & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ (1-\sum_{k=1}^{i} D_{K-1}) & 0 & 0 & \frac{1}{R_i} & 0 & 0 & 0 & 0 \\ \vdots & 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ (1-\sum_{k=1}^{j} D_{K-1}) & 0 & 0 & 0 & 0 & \frac{1}{R_j} & 0 & 0 \\ \vdots & 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ (1-\sum_{k=1}^{n} D_{K-1}) & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{R_k} \end{bmatrix} \begin{bmatrix} i \\ v_1 \\ \vdots \\ v_i \\ \vdots \\ v_j \\ \vdots \\ v_K \end{bmatrix} + \begin{bmatrix} 1 & \sum_{k=1}^{n} V_K & \cdots & \sum_{k=1}^{n-i} V_K & \cdots & \sum_{k=1}^{n-j} V_K & \cdots & V_1 \\ 0 & -I & 0 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & -I & -I & 0 & \cdots & 0 & \cdots & 0 \\ 0 & -I & -I & 0 & \cdots & 0 & \cdots & 0 \\ 0 & -I & -I & -I & \cdots & 0 & \cdots & 0 \\ 0 & -I & -I & -I & \cdots & 0 & \cdots & 0 \\ 0 & -I & -I & -I & \cdots & -I & \cdots & 0 \\ 0 & -I & -I & -I & \cdots & -I & \cdots & -I \end{bmatrix} \begin{bmatrix} \hat{v}_{in} \\ \hat{d}_0 \\ \vdots \\ \hat{d}_i \\ \vdots \\ \hat{d}_j \\ \vdots \\ \hat{d}_{K-1} \end{bmatrix} \quad (9)$$

Extracting transfer function from these equations:

$$\begin{cases} I(s) = \dfrac{1}{Ls + \sum\limits_{k=1}^{N} \left(\dfrac{R_k (1 - \sum\limits_{j=1}^{k} D_{j-1})^2}{1 + R_k C_k s} \right)} \\ V_k(s) = \dfrac{R_k (1 - \sum\limits_{j=1}^{k} D_{j-1}))}{1 + R_k C_k s} I(s) \end{cases} \quad (10)$$

Finally, the steady state equations for N output voltages would be:

$$V_k = \frac{R_K (1 - \sum D_{K-1}) V_{in}}{\sum R_K (1 - \sum D_{K-1})^2}, \quad I = \frac{V_{in}}{\sum R_K (1 - \sum D_{K-1})^2} \quad (11)$$

It is clear that different output voltages can be achieved based on different duty cycles.

6.4 Control System

Several current-mode control strategies have been conducted to improve the dynamic response of boost converters (Mammano, 1999; Siew-Chong et al., 2006). To have the potential of combining the advantages of the logical control and current mode control in a relatively simple controller realization for a MOB converter, a cross voltage control (V_T) with an internal hysteresis current control loop has been performed combined with mid point voltage (V_1) control. Fig. 19 illustrates the block diagram of the control method for a double-output boost converter. As shown, the solid loop is a cross voltage control with a hysteresis current control loop for the inductor current, in which the cross output of the MOB converter is controlled by switching the boost switch (S_0). The dashed loop is the mid point voltages control where the sharing switches (S_1) is forced to balance the capacitors' voltage. The current control loop consists of two cascaded control loops. The outer loop is a voltage control mode through which the reference current is modified based on voltage error to force this error to zero. The inner loop is the hysteresis current control which is the main loop that runs to forcibly constrain the inductor current between the hysteresis bands around the defined reference current.

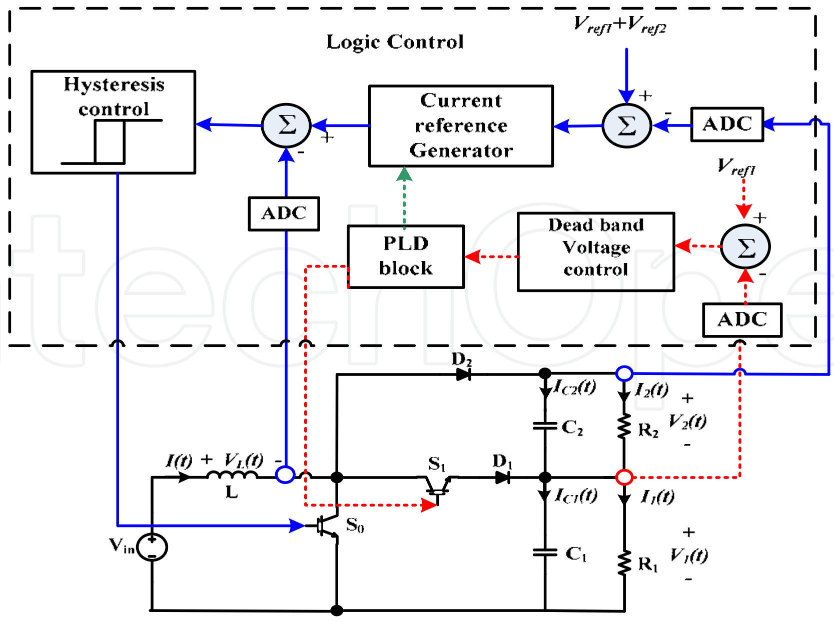
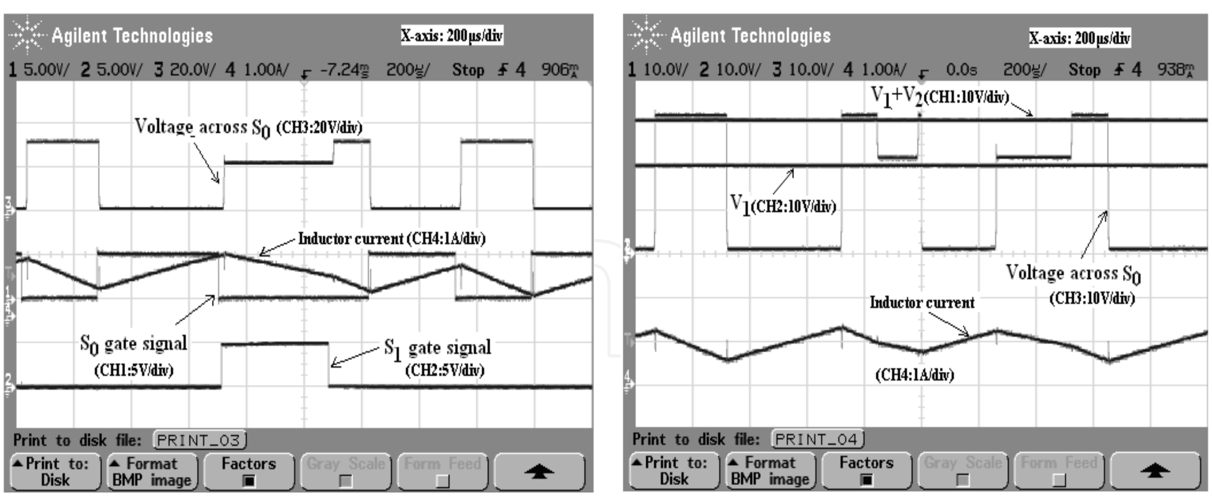


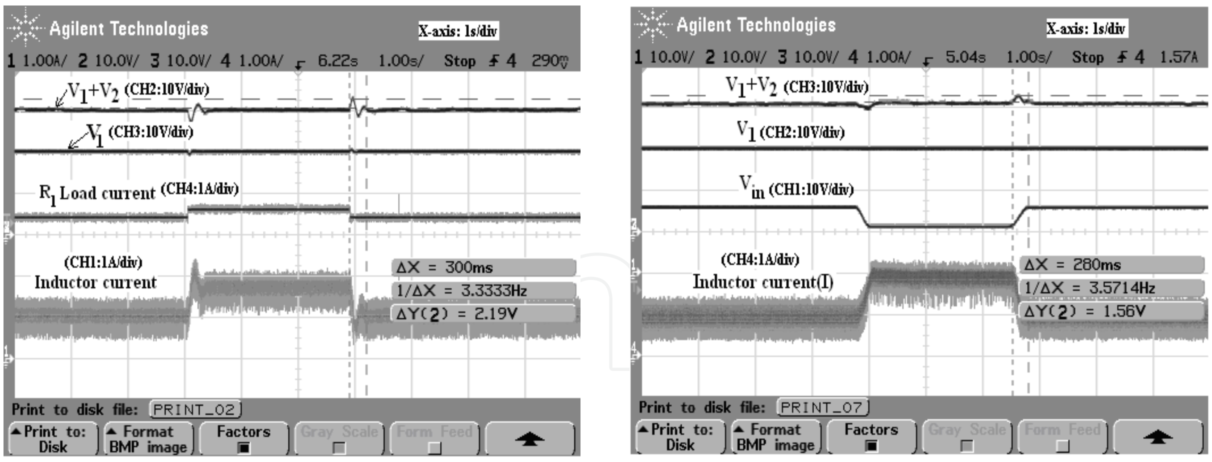
Fig. 19. Block diagram of the proposed control system

In the dead band voltage control block, the amount of the mid point voltage (V_1) error is compared in order to give priority to the voltage with larger error. Then the chosen mid point voltage will be compared with its defined voltage dead band (assumed 1% of reference) , if the voltage is higher (lower) than the upper (lower) dead band output signal of block changes to one (zero). It should be mentioned that defining the dead band can decrease unnecessary switching when the mid point voltage error is negligible; otherwise it can be set to zero to increase accuracy.



(a) (b)

Fig. 20. (a) Steady-state inductor current and switching pulses for the CCM operation (R_1 = 50 Ω and R_2=50 Ω). (b) Output voltages corresponding to (a).



(a) (b)

Fig. 21. Waveforms during transient condition. (a)When R_1 *is* changed. (b) Output voltage during input voltage disturbance (R_1=R_2=50 Ω).

The steady-state response under the proposed control scheme is shown in Fig. 20 form a laboratory prototype. The switching pulses (control signal) and the inductor current waveforms are shown to verify the control strategy for the Continues Conduction Mode (CCM) operation of the converter with load resistances of R_1=R_2=*50 Ω*. The mid point voltage (V_1) and total output (V_T), are assumed to be kept at *20V* and *30V* respectively, while V_{IN}=*15V*.

The control strategy is tested under disturbances in both load and input voltage, and the corresponding variations in the output voltage and inductor current are demonstrated in Fig. 21. In Fig. 21 (a) R_2=*50* and R_1 is varied from *50* to *35 Ω* and back. It is noted that the operation of the converter still remains in the CCM and the current modification applies in each five hysteresis cycles discontinuously. The output voltages display an undershoot (overshoot) for the load current increase (decrease), but they quickly settle around the reference value. Also, due to the switching options to control V_1 and V_2, the controlling of V_1 surpasses the other output, so that it has less undershoot and overshoot. While the converter is working with a load of R_1=R_2=*50 Ω* (CCM operation), a change in the input voltage from the *15V to 10 V* and back is applied. The change in the input voltage and the corresponding output-voltage waveforms are depicted in Fig. 21 (b). It is observed that the total output voltage shows small undershoot (overshoot) for the input voltage increase (decrease) and settles down after a short time. However, the mid point voltage remains constant, and the transients in voltage are sufficiently diminished.

6.5 Performance of Diode-clamped Joint with MOB Converter

The performance of the new single-phase diode-clamped inverters configuration is simulated in Fig. 22. Herein, on the DC-DC side, input voltage (V_{in}) is assumed as 100V; switching frequency of the DC-DC converter (f_{sw}) is 10 kHz, L=2mH, and C_1=C_2=1mF while on the inverter side fundamental and switching frequencies are f=50Hz, f_{sw}=4 KHz, and the DC link of the three-level diode-clamped inverter (V_{MN}) is boosted to 300 V by using a double-output boost converter. Carrier based PWM strategy has been carried out for the three-level diode-clamped converter to generate reference voltage. As shown in Fig. 22, while the total voltage of an inverter DC link is boosted at 300V, mid point voltages (V_1

$=V_{c1}$) are controlled at 150V to have an equal DC link capacitor voltage arrangement. The double-output boost converter can boost the low input voltage for DC link capacitors as well as balance the capacitors' voltage to the desired level for a high modulation index (Fig. 23), which is impossible without the capacitor voltage balancing algorithm in three-level diode-clamped converters with a passive front-end converter. Output voltage for the proposed configurations for m_a=1 and PF=0.95 is demonstrated in Fig. 22 and 23, respectively.

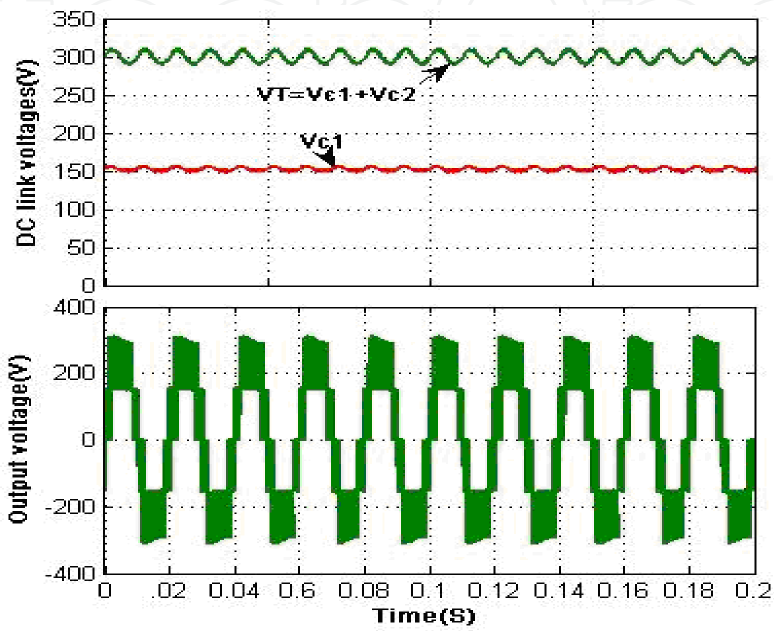


Fig. 22. Simulation results for DC link voltage of three-level diode-clamped Inverter with double-output boost converter

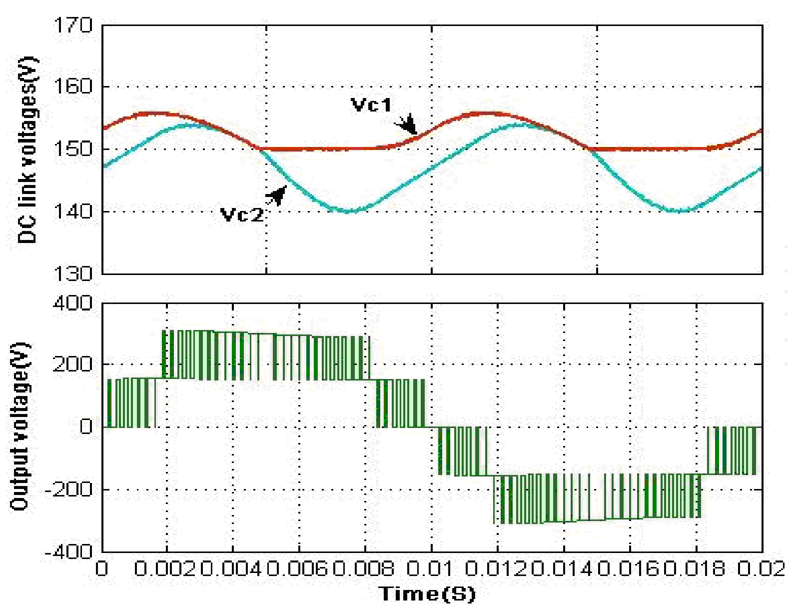


Fig. 23. Capacitor voltage balancing in three-level diode-clamped Inverter with double-output boost converter

7. Conclusion

In this chapter, different topologies for renewable energy systems based on power electronics converters have been studied. A new topology for a multi output DC-DC converter is presented in order to supply input voltages for a diode-clamp multilevel inverter. Using this circuit, the DC link voltages of the diode-clamped can be adjusted to a desired voltage level by the DC-DC converter, thereby solving the main problem associated with balancing the capacitor voltages in the diode-clamped topology. Furthermore, since the DC output voltage of PV or WT systems are not very high, this topology is a suitable candidate for these systems as it can boost the low and unregulated input voltage for a transformer less grid connection based on the multilevel topology. To verify the operation of this topology, both steady-state and small-signal ac models have been compared through simulation and hardware results.

8. References

Alepuz, S.; Busquets-Monge, S.; Bordonau, J.; Gago,J.; Gonzalez, D. & Balcells, J. (2006). Interfacing Renewable Energy Sources to the Utility Grid Using a Three-level Inverter. *IEEE Transaction on Industrial Electronics*, Vol. 53, No. 5, October 2006, 1504-1511, 0278-0046.

Alonso, O.; Sanchis, P.; Gubia, E. & Marroyo,L. (2003). Cascade H-bridge Multilevel converter for Grid-connected Photovoltaic Generators with Independent Maximum power point Power tracking of Each Solar Array. *Proceeding of IEEE Power Electronics Specialist Conference*, pp. 731-735, 0-7803-7754-0/03, 2003.

Bueno, E.J.; Cobreces, S.; Rodriguez, F.J.; Hernandez, A. & Espinaso, F. (2008). Design of NPC Back-to-Back Converter Interface for Wind Turbines with Squirrel-cage Induction Generator. *IEEE Transaction on Energy Conversion*, Vol. 23, No. 3, September 2008, 932-945.

Bum-Seok, S.; Sinha, G.; Manjrekar, M.D. & Lipo, T.A. (1998). Multilevel Power Conversion - An Overview of Topologies And Modulation Strategies, *Proceedings of the 6th International Conference on Optimization of Electrical and Electronic Equipments,* pp. AD-11-AD-24, 1998.

Busquets-Monge, S.; Rocabert, J.; Rodriguez, P.; Alepuz, S. & Bordonau, J. (2008). Multilevel Diode-clamped Converter for Photovoltaic Generators with Independent Voltage control of Each solar Array. *IEEE Transaction on Industrial Electronics*, Vol. 55, No. 7, July 2008, 2713-2723, 0278-0046.

Carrasco, J.M.; Franquelo, L.G.; Bialasiewicz, J.T.; Galvan, E.; Portillo Guisado, R.C.; Prats, Ma.A.; Leon, J.I. & Moreno-Alfonso, N. (2006). Power-Electronics Systems for the Grid Integration of Renewable Energy Sources: A Survey. *IEEE Transaction on Industrial Electronics*, Vol. 53, No. 4, August 2006, 1002-1016, 0278-0046.

Clasis, M. & Agelidis, V.G. (1998). Multilevel converters for Single-phase Grid connected Photovoltaic systems-An Overview, *Proceeding of IEEE International symposium on Industrial Electronics*, pp. 224-229, 0-7803-4756-0, South Africa,1998.

Gu, Y.; Hang, L.; Chen, H.; Lu, Zh.; Qian,Zh. and Li, J. (2005). A simple structure of LLC resonant DC-DC Converter for Multi-output Application. *Proceeding of IEEE Applied Power Electronics Conference*, pp. 1485-1490, 0-7803-8975-1/05 , March 2005.

Leon, J. I.; Portillo, R.; Vazquez, S.; Padilla, J.J; Franquelo,L.J & Carrasco, J.M. (2008). Simple Unified Approach to Develop a Time-Domain Modulation Strategy for Single-Phase Multilevel Converters. IEEE Transactions on Industrial Electronics, Vol. 55, No. 9, Spetember 2008 3239 - 3248.

Lopez, O.; Teodorescu, R. & Doval-Gandoy, J. (2006). Multilevel Transformerless Topologies for Single-Phase Grid-Connected Converters. *Proceeding of IEEE Industrial Electronics Conference,* pp. 5191-5196, 1-4244-0390-1, 2006.

Mammano, R. (1999). Switching Power Supply Topology Voltage Mode vs. Current Mode. *Texas Instruments Incorporated*, 1999.

Manjrekar, M.D.; Lund, R.; Steimer, P.; and Lipo, T.A. (2000). Hybrid Multilevel Power conversion system: A Competitive Solution for High Power Applications. *IEEE Transaction on Industrial Applications*, Vol. 36, No. 3, May/June 2000, 834-841.

Marchesoni, M. & Tenca, P. (2002). Diode-clamped Multilevel Converters: A Practicable Way to Balance DC-Link Voltages. *IEEE Transactions on Industrial Electronics,* Vol. 49, No. 4, August 2002, 752-765, 0278-0046.

Meynard, T.A. & Foch, H. (1992). Multi-level Conversion: High Voltage chopper and Voltage-source Inverter, *Proceeding of IEEE Power Electronics Specialist Conference*, pp. 397-403, Toledo Spain, 1992.

Myrzik, J.M.A. & Calais, M. (2003). String Module Integrated Inverters for Single-phase Grid Connected Photovoltaic Systems-A Review. *Proceeding of IEEE PowerTech Conference*, 8 pp, 0-7803-7967-5/03, Bologna Italy, 2003.

Nabae, A.; Takahashi, I, & Akagi, H. (1981). A new neutral-point-clamped PWM inverter. *IEEE Transaction on Industrial Electronic*, Vol. 1A-17, No. 5, 518–523.

Nami, A. & Zare, F. (2008). A New Random Current Control Technique for a Single-Phase Inverter with Bipolar and Unipolar Modulations. *IEEJ Transactions on Industry Applications*, Vol.128-D, No.4, 2008.

Nami, A.; Zare, F.; Ledwich, G.; Ghosh, A. & Blaabjerg, F. (2007). A new configuration for multilevel converters with diode clamped topology, *proceeding of IEEE International Power Engineering Conference*, pp. 661-665, 978-981-05-9423-7, Singapore, 2007.

Nami, A.; Zare, F.; Ledwich, G.; Ghosh, A. & Blaabjerg, F. (2008). Comparison between Symmetrical and Asymmetrical Single Phase Multilevel Inverter with Diode-Clamped Topology. *Proceeding in IEEE Power Electronics Specialists Conference*, pp.2921-2926, 978-1-4244-1668/08, Rhodes Island Greece, June 2008.

Rodriguez, J.; Jai, J.Sh. & Peng, F.Zh. (2002). Multilevel Inverters: A Survey of Topologies, Controls, and Applications. *IEEE Transaction on Industrial Electronics*, Vol. 49, No. 4, August 2002, 724-738, 0278-0046.

Sharma, R. & Hongwei.G. (2006). A new DC-DC converter for fuel cell powered distributed residential power generation systems, Proceeding of IEEE *Applied Power Electronics Conference and Exposition,* p. 1014-1018, 0-7803-9547-6 ,March 2006.

Siew-Chong, T.; Lai, Y.M. & Tse,C.K. (2006). Implementation of pulse-width-modulation based sliding mode controller for boost converters. *IEEE Power Electronics Letters,* Vol. 3, 130-135, December 2006, 1540-7985.

Tolbert, L.M. & Peng, F.Z. (2000). Multilevel Converters as a Utility Interface for Renewable Energy Systems, *Proceeding of IEEE Power Engineering Society*, pp. 1271-1274, 0-7803-6420-1, USA, 2000.

Yazdani, A. & Iravani, R. (2005). A Generalized State-Space Averaged Model of the Three-level NPC Converter for Systematic DC-Voltage-Balancer and Current-Controller Design. *IEEE Transactions on Power Delivery,* Vol. 20, No. 2, April 2005, 1105-1114, 0885-8977.

Yunxiang, X. and Jiuchao, G. (2004). Study on the Voltage Stability of Multi-output Converters. *Proceeding of IEEE The International Power Electronics and Motion Control Conference*, pp. 482-486, 7-5605-1869-9, August 2004.

Zare, F. & Ledwich, G. (2002). A hysteresis current control for single-phase multilevel voltage source inverters: PLD implementation. *IEEE Transactions on Power Electronics*, Vol. 17, No. 5, Sep 2002, 731 –738.

Zare, F. & Ledwich, G. (2008). A new predictive current control technique for multilevel converters. *Australian Journal of Electrical & Electronics Engineering (AJEEE)*, 2008, Vol. 4, No. 1, 2008, 25-35.

Zare, F. (2008). Power Electronics Education E-Book. www.Peeeb.com, ISBN: 978-0-646-49442-5.

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Renewable Energy is energy generated from natural resources-such as sunlight, wind, rain, tides and geothermal heat-which are naturally replenished. In 2008, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, such as wood burning. Hydroelectricity was the next largest renewable source, providing 3% (15% of global electricity generation), followed by solar hot water/heating, which contributed with 1.3%. Modern technologies, such as geothermal energy, wind power, solar power, and ocean energy together provided some 0.8% of final energy consumption. The book provides a forum for dissemination and exchange of up-to-date scientific information on theoretical, generic and applied areas of knowledge. The topics deal with new devices and circuits for energy systems, photovoltaic and solar thermal, wind energy systems, tidal and wave energy, fuel cell systems, bio energy and geo-energy, sustainable energy resources and systems, energy storage systems, energy market management and economics, off-grid isolated energy systems, energy in transportation systems, energy resources for portable electronics, intelligent energy power transmission, distribution and inter-connectors, energy efficient utilization, environmental issues, energy harvesting, nanotechnology in energy, policy issues on renewable energy, building design, power electronics in energy conversion, new materials for energy resources, and RF and magnetic field energy devices.

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